EXPERIMENTAL AND SIMULATION ANALYSIS FOR PERFORMANCE ENHANCEMENT OF ELLIPTICAL SAVONIUS WIND TURBINE BY MODIFYING BLADE SHAPES

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ABSTRACT

Savonius turbines are drag-based rotors which operate due to a pressure difference between the advancing and retreating blades. After going through an exhaustive literature review, it was realized that the Savonius wind turbines are an applicable option at low wind speed areas, where the counterpart of these turbines cannot work efficiently. Nevertheless, the existing design is still under research to make it more applicable in urban areas. Therefore, the research objective was to develop and test an elliptical Savonius wind turbine to improving its performance in terms of power and torque coefficients by modifying blade shapes and overlap ratio. In the beginning, a series of 2D unsteady simulations (CFD-Fluent version 19.1) of the Savonius elliptical turbine has been performed to study the overlap ratio of blades and the effect of the turbulence models. Conventional elliptical Savonius turbine was modified by changing the overlap ratio from the value (OR=0.15) to (OR=0.2) and called as the Model-A. Then, the concave surface of the blade Model-A was modified (as zigzag shape) and called as Model-B. The blade shape of the Model-B was modified by adding bypass channels for each blade to creating new configuration was called the Model-C. The experimental work begins with the manufacturing of the models (A, B and C) of the blade using 3D printing technology. Models were tested by the wind tunnel in Aerodynamic laboratory (UTHM) with four cases of wind velocity. 2D simulation result for Model-A at OR= 0.2, where the increase in maximum power coefficient value obtained was 3.85% and 7.69% compared to overlap ratio (0.15 and 0.1), respectively. The result of the experimental test was obtained the maximum power coefficient (0.296, 0.292, 0.291, and 0.295) at wind velocity (6 m/s, 8 m/s, 9 m/s, and 10 m/s), respectively for Model-B. The Model-C result in the maximum power coefficient (0.28) compared with Model-A (0.26). The 3D unsteady simulation also has been done to visualisation the behaviour of flow around Model-B and it show a good agreement with experimental test results.

ABSTRAK

Turbin Savonius adalah rotor berasaskan seret yang beroperasi disebabkan oleh perbezaan tekanan antara bilah pemaju dan pengunduran. Selepas melalui kajian literatur yang menyeluruh, ternyata bahawa turbin angin Savonius adalah pilihan yang sesuai di kawasan angin laju dipermukaan yang rendah, di mana rakan sejana turbin ini tidak dapat berfungsi dengan cekap. Walau bagaimanapun, reka bentuk yang sedia ada masih dalam penyelidikan untuk menjadikannya lebih sesuai di kawasan bandar. Oleh hal yang demikian, objektif penyelidikan adalah untuk membangun dan menguji turbin angin Savoyus elips untuk meningkatkan prestasinya dari segi kuasa dan koefisien tork dengan mengubah bentuk bilah dan nisbah pertindihan. Pada mulanya, satu siri 2D simulasi yang tidak mantap (CFD-Fluent versi 19.1) dari turbin elips Savonius telah dilakukan untuk mengkaji nisbah pertindihan bilah dan kesan model pergolakan. Turbin unggun konvensional konvensional Savonius diubahsuai dengan menukar nisbah bertindih daripada nilai (OR = 0.15) ke (OR = 0.2) dan dipanggil sebagai Model-A. Kemudian, permukaan cekung pada bilah Model-A diubahsuai (sebagai bentuk zigzag) dan dikenali sebagai Model-B. Bentuk bilah Model-B diubahsuai dengan menambah saluran pintasan untuk setiap bilah untuk membuat konfigurasi baru dipanggil Model-C. Kerja eksperimen bermula dengan pembuatan model (A, B dan C) bilah menggunakan teknologi percetakan 3D. Model telah diuji oleh terowong angin di makmal Aerodinamik (UTHM) dengan empat kes kelajuan angin. Hasil simulasi 2D untuk Model-A pada OR = 0.2, di mana peningkatan nilai koefisien maksimum yang diperoleh adalah 3.85% dan 7.69% berbanding dengan nisbah tertindih (0.15 dan 0.1). Keputusan uji kaji eksperimen diperolehi dengan pekali kuasa maksimum (0.296, 0.292, 0.291, dan 0.295) pada kelajuan angin (6 m / s, 8 m / s, 9 m / s, dan 10 m / s) masing-masing untuk Model-B. Model-C menghasilkan pekali kuasa maksimum (0.28) berbanding Model-A (0.26). Simulasi tidak stabil 3D juga telah dilakukan untuk menggambarkan kelakuan aliran di sekitar Model-B dan ia menunjukkan persetujuan yang baik dengan hasil ujian eksperimen.

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LIST OF SYMBOLS AND ABBREVIATIONS

Abbreviations

AR	-	Aspect ratio
CFD	-	Computational fluid dynamics
HAWT	-	Horizontal axis wind turbine
H-Rotor	-	VAWT with straight blades
OR	-	Overlap ratio
RPM	-	Revolution per minute [N]
SINPLE	-	Semi implicit linked equations
SST	-	Shear stress transport
TSR	-	Tip-speed ratio [λ]
VAWT	-	Vertical axis wind turbine

Notations

A	-	Swept area of the turbine [m^2]
d	-	Chord length of the blades [m]
D	-	Outer diameter of the turbine [m]
D_o	-	End plate diameter [m]
e	-	Blade overlap distance [m]
H	-	Blade height [m]
F	-	Force [N]
I	-	Electric current [Amp]
k	-	Turbulence kinetic energy [$m^2\ s^{-2}$]
P	-	Pressure [Pascal]
P *available*	-	Power available in the wind [w]
P_f	-	Power coefficient
P *turbine*	-	Turbine power output [w]

R	-	Rotor radius [m]
Re	-	Reynolds number
s	-	Separation Gap [m]
T	-	Dynamic Torque [Nm]
T_f	-	Torque coefficient
U	-	Free stream wind speed [m/s]
V		Electric voltage [volt]

Greek symbols

ε	-	Energy dissipation rate [m^2 s^{-2}]
σ	-	Turbine solidity
ρ	-	Density of air (kg/m^3)
μ	-	Dynamic viscosity [kg/(m s)]
θ	-	Turbine rotational angle [°]
η_{Gen}	-	Generator efficiency
ω	-	Angular speed of the turbine [Rad/s]

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CHAPTER 1

INTRODUCTION

In previous years, there has been increasing interest in the sustainable generation of electricity due to the uncontrolled exploitation of conventional energy resources which as well as issues related to energy production such as environmental pollution and global warming. As a result, interest in energy issues has shifted to the search for alternative sources such as solar, tide, biomass and wind energy. This has been reviewed and studied in terms of the size of power plants and the direction of the transformation of central electric stations to small stations distributed throughout the country as well as the conversion of energy produced by wind energy. To achieve the highest possible level of electric power production, wind turbines were properly installed to be in the wind farm.

The analysis also showed that most nationally determined contribution (NDCs) underestimated the potential of renewable energy, the technological learning rate, rapid cost reductions and innovation that were bound to continue over the coming years. With more ambitious yet credible commitment to renewable energy, by year 2030, renewables can achieve up to five times the carbon dioxide (CO_2) mitigation reflected in current NDCs. Combined with significant energy efficiency gains, further reliance on renewable energy could halve the estimated annual carbon dioxide (CO_2) emissions to about 20 giga tonnes (Gt) in 2030. This would be enough to keep the world on a $2C^{\circ}$ pathway, with continuing advances thereafter (see Figure 1.1) (Adnan Z. Amin, 2017). Therefore, researchers focused on studying the use of wind energy to take advantage of the disposal of CO_2 pollutants and obtain the maximum electric power from them. There are two main types of WTs, which are the horizontal axis wind turbines (HAWT) and the vertical axis wind turbines (VAWT), where each of these WTs has their respective advantages and disadvantages. In comparison to HAWT, catching the wind from all directions is the major feature of VAWT, which does not require the yaw mechanism (Li et al., 2016; Ross & Altman, 2011). With a simple structure, less commotion and little operation space, VAWT is more appropriate for urban zones where the wind stream is exceedingly turbulent and conflicting (Bhutta et al., 2012; Rashidi, Kadambi, & Chinchore, 2014). Nonetheless, the main problems of the VAWT consist of having small efficiency and difficult self-starting (Bhutta et al., 2012; Eriksson, Bernhoff, & Leijon, 2008).

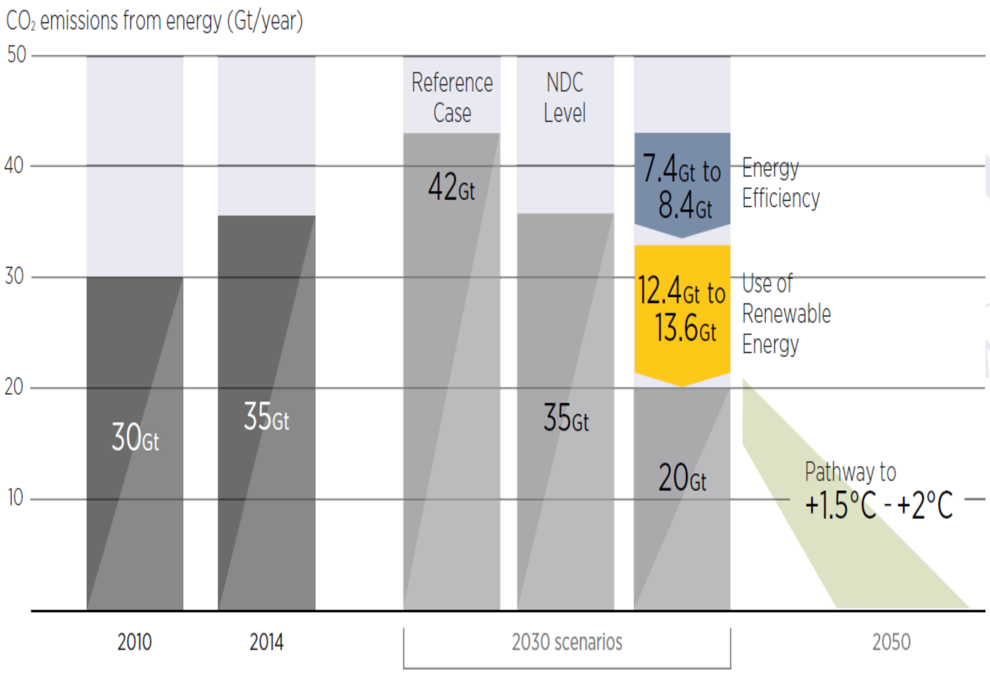

Figure 1.1: Global energy-related (CO_2) emissions between 2010 to 2050 (Adnan Z. Amin -Director-General/ IRENA, 2017)

1.1 Background of the Study

The two fundamentals of wind turbines are the HAWTs and VAWTs. Every single model of wind turbine, for the most part, belongs to one of these classifications. However, the world market is ruled by HAWT. Different plans have been proposed in the past to lessen the cost and increase the performance of wind turbines. The division of types of wind turbines depends on the direction of shaft rotation relative to the earth's surface, where the HAWT rotation shaft is parallel to the ground surface. In contrast, the turbines of the VAWT are perpendicular to the surface of the earth as shown in Figure 1.2 (Kozak, 2014).

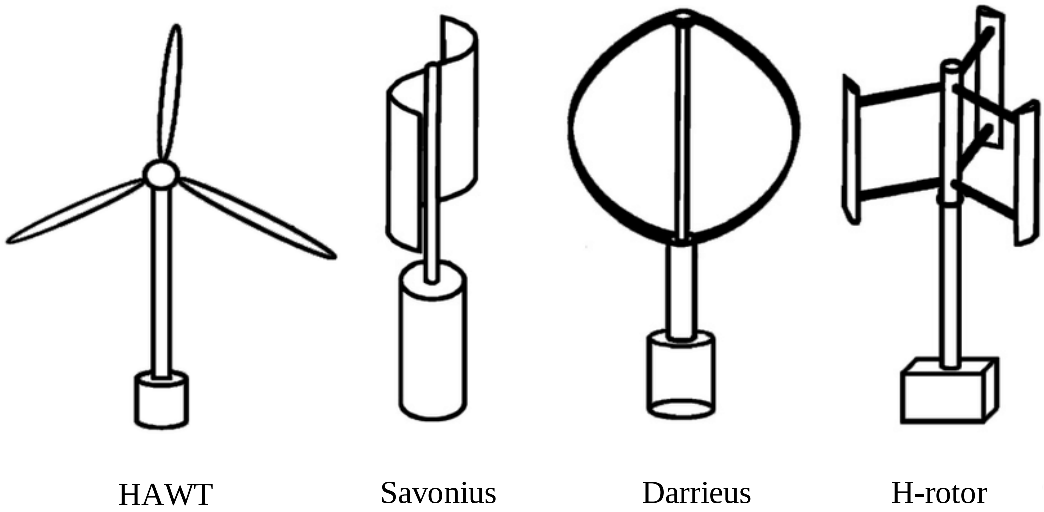

Figure 1. 2: Wind turbines: HAWT Type and VAWTs Types (Kozak, 2014)

Global wind power generation amounted to 950 TWh in 2016, which was nearly 4% of the total global power generation. Some countries have reached much higher percentages. Denmark produced 42% of its electricity from wind turbines in 2016, the highest figure yet recorded worldwide. In Germany, wind power contributed a new record of 13% of the country’s power demand from 2001 to 2016 as shown in Figure 1.3 (Wong et al., 2017).

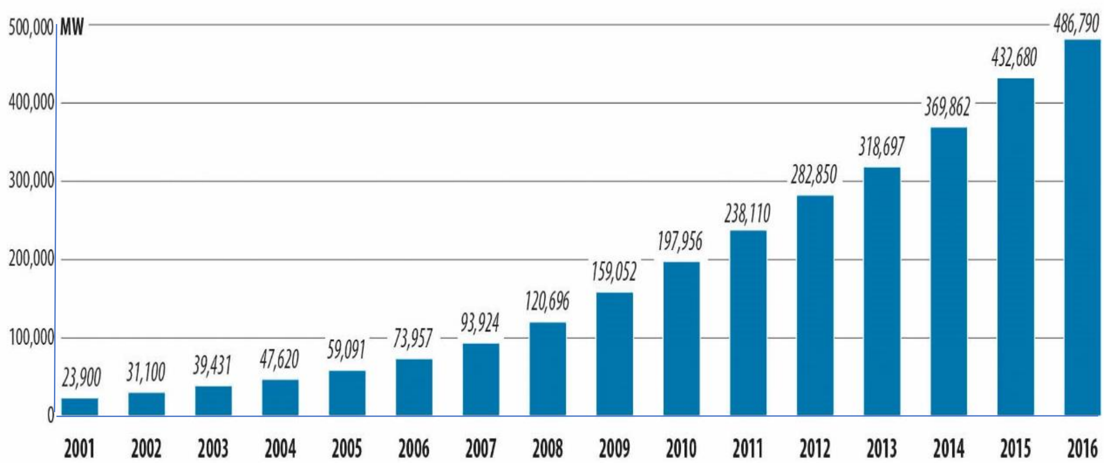

Figure 1.3: Annual net global wind capacity additions, 2001-2016 (Wong et al., 2017).

There are numerous features of VAWTs which are different to HAWTs. Studies have shown that VAWTs are more appropriate for turbulent flows and urban applications. However, the low total efficiency and low self-start capability of VAWTs are always major disadvantages, mostly for the lift-type VAWTs. Unlike HAWTs, the blade rotation for VAWTs do not generally give positive torque (Wong et al., 2017).

1.1.1 Horizontal Axis Wind Turbine (HAWT) Type

Over the past several years, wind farms generate electricity using HAWTs, which has the highest coefficient of power compared to any other turbines, leading it to be widely used. As shown in Figure 1.4, the general disadvantages of the (HAWT) are the complex structure of the mechanical and electrical parts which require high maintenance, even though it is more efficient than VAWT.

The second problem is the adoption of HAWT at the height of the tower, where the higher the tower, the higher the surface of the earth which then produces more energy. As the rotor and the mechanical and electrical parts are positioned at the top of the tower, the installation and maintenance of the parts incur a higher cost (Spera, 2009). The best increases in mechanical wind capacity can be benefited from the HAWT, by modifying the design of the three-blade turbine. The cross-movement of the tethered blades attracts more attraction on the dynamic energy to reach fast wind flows at the highest altitude (Cherubini, Antonello and Papini, Andrea and Vertechy, Rocco and Fontana, 2015; Goldstein, 2013).

In addition to large wind farms, increasing awareness among people towards clean energy has led to a growing interest in wind energy harvesting within the built environment in an urban area. The complex terrain of the buildings causes a strong deflection of the incoming wind direction. VAWT was identified as the most suitable wind energy extractor under such conditions due to its independence from wind direction in which no yaw mechanism is required. It is well-known that this type of turbine shows lower efficiency and increased oscillations when compared to its horizontal axis competitor. However, the most obvious advantages are its simple design, low cost and operability even in winds of highly changeable intensity and direction which makes them very appealing for both developed urban environments as well as less developed rural regions that are difficult to access (Svorcan, Stupar, Komarov, Peković, & Kostić, 2013).

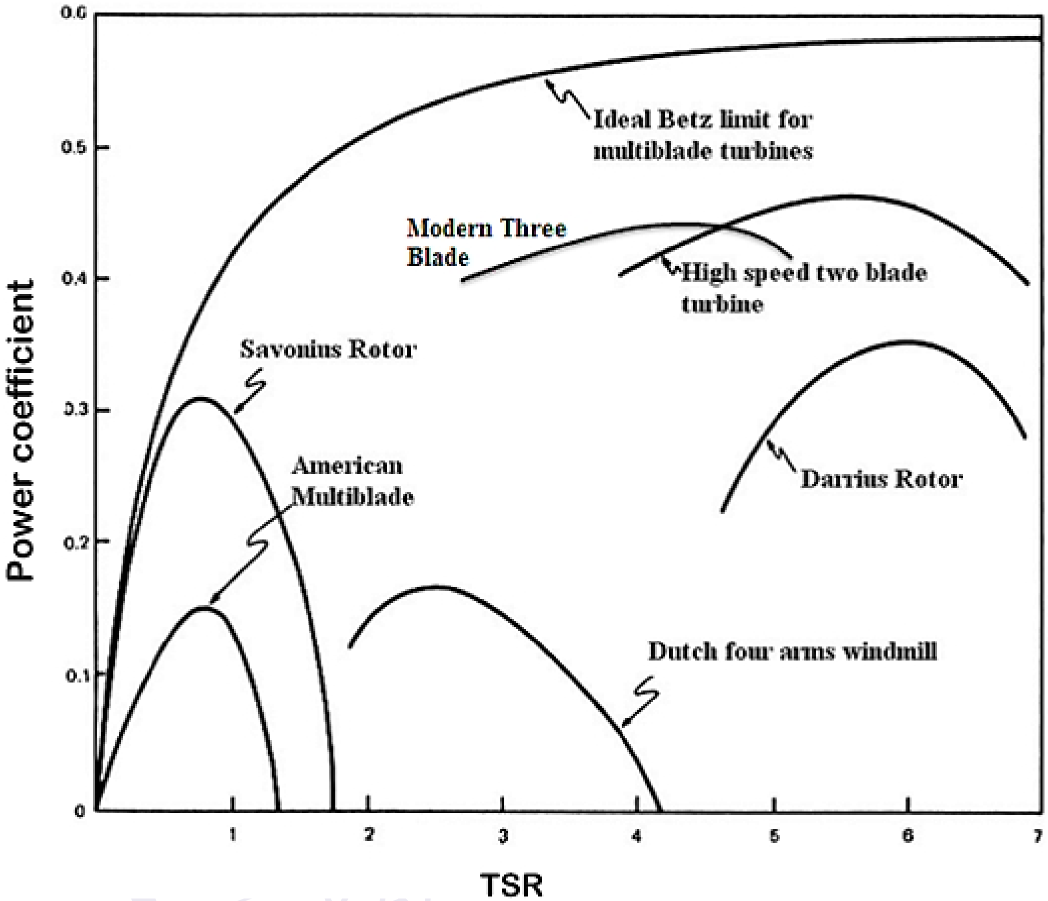

Figure 1.4: Rotor efficiency against TSR for different types of turbines (Spera, 2009)

1.1.2 Darriues Turbines

Darriues turbines are a type of VAWT that depends on the lift force and mechanism action of the designer, based on the aerodynamics precept of an aircraft. This invention was carried out by F. M. Darrieus (1930) (Devine-Wright, 2005). The airfoil considered in the cross-section of the blades was designed so that the wind would leave longer on the convex side than the other concave side. Therefore, it produces wind speed at its relative value on the convex side. Whether Bernoulli's equation was used or not, it will create differential pressure due to a difference in the wind velocity on the airfoil which in turn will pull its rotor blade around as the wind passes the turbine. Darrieus-type wind turbines consist of two or more rotary blades as shown in Figure

1.6. The rotational speed of Darrieus is high but it requires a high start-up velocity which can be synchronized and combined with an electric generator. Darrieus has a high power efficiency compared to other vertical axis wind turbines based on the drag force. The main problem for Darrieus is the high start-up speed. This has led to the trend of many researchers numerically and experimentally studying the combination of the Savonius rotor and Darrieus rotor to make a hybrid design to acknowledge the Savonius's starting speed (Kang, Liu, & Yang, 2014).

Some researchers have focused on a range of wind turbines in various developed countries to develop and improve VAWT's performance efficiency. These research studies included the development of blade design or the fashioning of vertical axis wind turbines. According to Elkhoury, Kiwata and Aoun (2015), the rotor model H was improved with a variable pitch so that the vertical wind turbine blades can adjust the angle of the pitch to make it spin slightly, resulting in the attack of wind currents in a different angle. Access was increased in the P_f at all values of the TSR. There were also other similar studies regarding the improvement (Chougule, Rosendahl, & Nielsen, 2015; Zeiner-Gundersen, 2014).

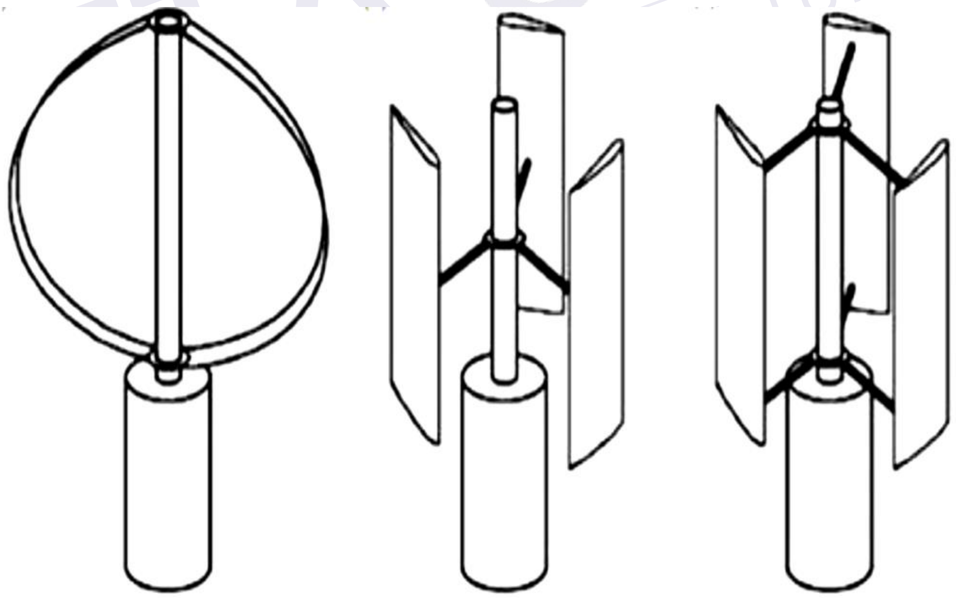

Figure 1.5: Darriues turbine types (MacPhee & Beyene, 2012)

It is possible to modify the values of the lifting coefficient of a blade through a change in the angle of a blade. This has resulted in an improved performance and had increased the P_f value of about 43% when compared to the traditional model air foil blade. (Chougule et al., 2015). Apart from that, a new model for the Savonius rotor was designed using moving blades that were curved to eliminate negative torque and to improve the dynamic performance. The mechanical design was to make the blades open when the blade reverts to the passage of air when the pressure changes on the sides of a rotor (Reupke & Probert, 1991).

A proposal to study a new model of the H-rotor wind turbine for the purpose of developing the rotor capacity for self-starting through the use of internal and external openings in rotor blades was performed. The results of the tests showed that the design had a negative effect on the value of P_f (Chen, Yang, Yang, & Xu, 2015).

Besides that, a study focusing on the modification of the Darrieus Type-H to increase the mechanical torque coefficients of the turbine was conducted. Positive results were obtained by increasing the force rate of oblique to (40%) (Ismail & Vijayaraghavan, 2015).

1.2 Problem Statement

The need for improved alternative energy sources is ever prevalent. Wind energy is one of the most viable renewable sources today due to its year-round availability, and pollution-free nature. However, research of VAWTs has gained a growing interest in recent years because of the opportunities available for small-scale and off-grid power generation which favours the use of vertical-axis turbines.

Savonius wind turbine is a type of vertical axis wind turbine which are drag-based rotors which operate due to a pressure difference between the advancing and retreating blades. The rotor part is a component of a wind turbine which converts the flow of an air mass into mechanical rotational energy. Therefore, this component together with its interface with other components is of utmost importance. Its fabrication and utilization depend on prevalent wind speeds at the site of installation, its costs and also the quality of the manufacturer. For small domestic applications in low wind speed areas, the use of a low-cost wind turbine that can operate in a low wind regime would be desirable. Unfortunately, there are substantial problems in the Savonius rotor. It is worth noting that the performance efficiency is lower compared to the horizontal axis wind turbine as well as negative torque on the return blade.

The Savonius turbines have a self-starting speed in urban area under low wind speed, but the main problem that causes the reduced performance efficiency of the Savonius rotor is that it has a high negative torque at the return blade. Therefore, the design and testing of three-dimensional models of Savonius (vertical axis wind turbines) printed in this work are presented, by the focus on the geometric parameter of the blade shape and improve the gap between the two blades.

1.3 Objectives

The goal of this study is developing Savonius blades an effective and easy to fabricate by using 3D printer technology, also by a low-cost method of recording the experimental data. Therefore, this thesis embarks on the following objectives while achieving the aim of this research:

1. To determine the best of overlap ratio (OR), which affecting on Savonius wind turbine performance.
2. To develop a blade shapes by modifying the concave blade surface as a zigzag surface to increase positive torque and adding four bypass channels in each blade.
3. To compare the new model with a publisher previous model in terms of power coefficient and torque coefficient.

1.4 Scope of Study

The scopes of this research are set forth as follows:

1. Validation and verification of the 2D unsteady simulations (CFD-Fluent) of the Savonius elliptical turbine to determine the effect of the turbulence models, overlap ratio, and a number of elements (Mesh Ansys). Given the results of the numerical simulation, geometry parameters were adopted to design three models of the blade to prepare it for experimental work.

2. Design new Savonius turbine models based on the optimum parameters by researches and previous studies, drawing the models using the SolidWorks program, as shown below:

   a) Conventional elliptical Savonius turbine was modified by changing the overlap ratio from the value (OR=0.15) to (OR=0.2) and called as the Model-A.
   b) The concave surface of the blade Model-A was modified (as zigzag shape) to increase its surface area and called as Model-B.
   c) The blade shape of the Model-B was modified by adding bypass channels for each blade to creating new configuration was called the Model-C.

3. Manufacturing the new models of the Savonius rotor after obtaining optimal parameters by using the 3D printer technology for the purpose of experimental testing.
4. An experimental test of the new models via open wind tunnel subsonic at different values of wind speeds in order to obtain the values of the maximum power coefficient. New method is used to record experimental data by making a digital control panel.
5. Comparative of the results of the experimental test with 3D unsteady simulations (CFD-Fluent version 19.1).

1.5 Outline of the Study

The thesis has been organized into five chapters, the details of which are summarized below:

Chapter 1: This chapter presents the background of the wind turbine and the current issues related to this study.

Chapter 2: This chapter presents the principle of the work of the Savonius turbine as well as an overview of previous researches in this area.

Chapter 3: This chapter illustrates the research methodology applied in this study which includes five subtopics such as 2D unsteady simulation of the geometry parameters for their adoption in this study; the manufacturing of new models;

REFERENCES

Adnan Z. Amin -Director-Genera/ IRENA. (2017). REthinking Energy. In *REthinking Energy 2017: Accelerating the global energy transformation* (Vol. 55). Director-General IRENA.

Ahmadi-Baloutaki, M., Carriveau, R., & Ting, D. S. K. (2016). A wind tunnel study on the aerodynamic interaction of vertical axis wind turbines in array configurations. *Renewable Energy*, *96*, 904–913.

Al-Faruk, A., & Sharifian, A. S. (2015). Effects of flow parameters on the performance of vertical axis swirling type Savonius wind turbine. *International Journal of Automotive and Mechanical Engineering (IJAME)*, *12*(December), 2929–2943.

Al-Faruk, A, Sharifian, S. A., & Al-Atresh, S. (2012). Numerical investigation of performance of a new type of Savonius turbine. *Proceedings of the 18th Australasian Fluid Mechanics Conference (AFMC 2012)*, 1–4.

Al-Faruk, Abdullah, & Sharifian, A. (2016). Geometrical optimization of a swirling Savonius wind turbine using an open jet wind tunnel. *Alexandria Engineering Journal*, *55*(3), 2055–2064.

Al-Kayiem, H. H., Bhayo, B. A., & Assadi, M. (2016). Comparative critique on the design parameters and their effect on the performance of S-rotors. *Renewable Energy*, *99*, 1306–1317.

Alaimo, A., Esposito, A., Messineo, A., Orlando, C., & Tumino, D. (2015). 3D CFD analysis of a vertical axis wind turbine. *Energies -Multidisciplinary Digital Publishing Institute*, *8*(4), 3013–3033.

Alam, F., & Golde, S. (2013). An aerodynamic study of a micro scale vertical axis wind turbine. *Procedia Engineering - Elsevier*, *56*, 568-572-

Ali, A., Golde, S., Alam, F., & Moria, H. (2012). Experimental and computational study of a micro vertical axis wind turbine. *Procedia Engineering*, *49*(1877–7058), 254–262.

Alom, N., Borah, B., & Saha, U. K. (2018). An insight into the drag and lift characteristics of modified Bach and Benesh profiles of Savonius rotor. *Energy Procedia /Elsevier*, *144*, 50–56.

Alom, N., Kolaparthi, S. C., Gadde, S. C., & Saha, U. K. (2016). Aerodynamic design optimization of elliptical-bladed Savonius-style wind turbine by numerical simulations. *ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering*, V006T09A009--V006T09A009.

Alom, N., Kumar, N., & Saha, U. K. (2018). Aerodynamic performance of an elliptical-bladed savonius rotor under the influence of number of blades and shaft. *The ASME 2017 Gas Turbine India Conference GTINDIA2017*, 1–11.

Alom, N., & Saha, U. K. (2018). Performance evaluation of vent-augmented elliptical-bladed savonius rotors by numerical simulation and wind tunnel experiments. *Energy*, *152*, 277–290.

Amiri, M., & Anbarsooz, M. (2019). Improving the Energy Conversion Efficiency of a Savonius Rotor Using Automatic Valves. *Journal of Solar Energy Engineering*, *141*(3), 031017.

Amiri, M., Teymourtash, A., & Kahrom, M. (2017). Experimental and numerical investigations on the aerodynamic performance of a pivoted Savonius wind turbine. *Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *231*(2), 87–101.

Anbarsooz, M. (2016b). Aerodynamic performance of helical Savonius wind rotors with 30^{o} and 45^{o} twist angles: experimental and numerical studies. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, *230*(6), 523–534.

Antar, E., & Elkhoury, M. (2019). Parametric sizing optimization process of a casing for a Savonius Vertical Axis Wind Turbine. *Renewable Energy - Elsevier*, 127–138.

Bachu, D., Gupta, R., & Misra, R. (2014). Experimental Analysis of a 20° Twist Helical Savonius Rotor at Different Overlap Conditions. *Applied Mechanics and Materials - Trans Tech Publ*, *592–594*, 1060–1064.

Backman, J., Hansen-haug, M., Laaksonen, M., Alkki, M., & Aura, P. (2018). Experimental and numerical analysis of vaned wind turbine performance and fl ow phenomena. *Energy,Elsevier*, *159*(827–841).

Bai, H. L., Chan, C. M., Zhu, X. M., & Li, K. M. (2019). A numerical study on the performance of a Savonius-type vertical-axis wind turbine in a confined long channel. *Renewable Energy*, *139*, 102–109.

Benesh, A H. (1988). Wind turbine system using a vertical axis savonius-type rotor. *Google Patents / US Patent 4,784,568*. Retrieved from https://www.google.com/patents/US4784568

Benesh, Alvin H. (1996). Wind turbine with savonius-type rotor. *Google Patents, US Patent*. Retrieved from https://www.google.com/patents/US5494407

Bhutta, M. M. A., Hayat, N., Farooq, A. U., Ali, Z., Jamil, S. R., & Hussain, Z. (2012). Vertical axis wind turbine--A review of various configurations and design techniques. *Renewable and Sustainable Energy Reviews*, *16*(4), 1926–1939.

Bhuyan, S., & Biswas, A. (2014). Investigations on self-starting and performance characteristics of simple H and hybrid H-Savonius vertical axis wind rotors. *Energy Conversion and Management*, *87*, 859–867.

Bouhal, T., Rajad, O., Kousksou, T., Arid, A., Rha, T. El, Jamil, A., & Benbassou, A. (2018). CFD performance enhancement of a low cut-in speed current Vertical Tidal Turbine through the nested hybridization of Savonius and Darrieus. *Energy Conversion and Management-Elsevier*, *169*(February), 266–278.

Chan, C. M., Bai, H. L., & He, D. Q. (2018). Blade shape optimization of the Savonius wind turbine using a genetic algorithm. *Applied Energy / Elsevier*, *213*(January), 148–157.

Chen, J., Yang, H., Yang, M., & Xu, H. (2015). The effect of the opening ratio and location on the performance of a novel vertical axis Darrieus turbine. *Energy - Elsevier*, *89*, 819–834.

Cherubini, Antonello and Papini, Andrea and Vertechy, Rocco and Fontana, M. (2015). Airborne Wind Energy Systems : A review of the technologies. *Renewable and Sustainable Energy Reviews / Elsevier*, *51*, 1461–1476.

Chong, W. T., Fazlizan, A., Poh, S. C., Pan, K. C., Hew, W. P., & Hsiao, F. B. (2013). The design, simulation and testing of an urban vertical axis wind turbine with the omni-direction-guide-vane. *Applied Energy*, *112*, 601–609.

Chougule, P. D., Rosendahl, L., & Nielsen, S. R. K. (2015). Experimental study of the effect of a slat angle on double-element airfoil and application in vertical axis wind turbine. *Ships and Offshore Structures - Taylor & Francis*, *10*(2), 176–182.

Dabiri, & J. O. (2011). Potential order-of-magnitude enhancement of wind farm power density via counter-rotating vertical-axis wind turbine arrays. *Journal of Renewable and Sustainable Energy*, *3*(4).

Damak, A., Driss, Z., & Abid, M. S. (2018). Journal of Wind Engineering & Industrial Aerodynamics Optimization of the helical Savonius rotor through wind tunnel experiments. *Journal of Wind Engineering & Industrial Aerodynamics-Elsevier*, *174*(December 2017), 80–93.

Deb, B., Gupta, R., & Misra, R. D. (2013). Performance analysis of a helical Savonius rotor without shaft at 45° twist angle using CFD. *Journal of Urban and Environmental Engineering*, *7*(1), 126–133.

Devine-Wright, P. (2005). Beyond NIMBYism: towards an integrated framework for understanding public perceptions of wind energy. *Wind Energy / Wiley Online Library*, *8*(2), 125–139.

Driss, Z., Damak, Abid, A. and, & Salah, M. (2015). Evaluation of the Savonius Wind Rotor Performance for Different External Overlap Ratios. *International Journal of Fluid Mechanics \& Thermal Sciences*, *1*(1), 14–19.

El-Askary, W. A., Nasef, M. H., AbdEL-hamid, A. A., & Gad, H. E. (2015). Harvesting wind energy for improving performance of savonius rotor. *Journal of Wind Engineering and Industrial Aerodynamics*, *139*, 8–15.

El-Askary, W. A., Saad, A. S., AbdelSalam, A. M., & Sakr, I. M. (2018). Journal of Wind Engineering & Industrial Aerodynamics Investigating the performance of a twisted modi fi ed Savonius rotor. *Journal of Wind Engineering & Industrial Aerodynamics*, *182*(April), 344–355.

Elbatran, A. H., Ahmed, Y. M., & Shehata, A. S. (2017). Performance study of ducted nozzle Savonius water turbine, comparison with conventional Savonius turbine. *Energy*, *134*, 566–584.

Elkhoury, M., Kiwata, T., & Aoun, E. (2015). Experimental and numerical investigation of a three-dimensional vertical-axis wind turbine with variable-pitch. *Journal of Wind Engineering and Industrial Aerodynamics - Elsevier*, *139*, 111-123

Elmabruk, A. M., & A, A. A. (2014). A New Experimental Technique for Measuring Both the Average and Instantaneous Torque of Savonius Wind Turbines. *The Fifth International Renewable Energy Congress IREC*, (March 25 ? 27, Hammamet, TUNISIA).

Eriksson, S., Bernhoff, H., & Leijon, M. (2008). Evaluation of different turbine concepts for wind power. *Renewable and Sustainable Energy Reviews*, *12*(5), 1419–1434.

Frikha, S., Driss, Z., Ayadi, E., Masmoudi, Z., & Abid, M. S. (2016). Numerical and experimental characterization of multi-stage Savonius rotors. *Energy - Elsevier*, *114*, 382–404.

Goh, S. C., Boopathy, S. R., Krishnaswami, C., & Schlüter, J. U. (2016). Tow testing of Savonius wind turbine above a bluff body complemented by CFD simulation. *Renewable Energy*, *87*, 332–345.

Goldstein, L. (2013). Theoretical analysis of an airborne wind energy conversion system with a ground generator and fast motion transfer. *Energy / Elsevier*, *55*, 987–995.

Goundar, J. N., Ahmed, M. R., & Lee, Y.-H. (2018). Design and Optimization of a Ducted Marine Current Savonius Turbine for Gun-Barrel Passage, Fiji. *Journal of Offshore Mechanics and Arctic Engineering*, *141*(2), 021901.

Gupta, R., & Sharma, K. (2011). Flow Physics of a Three-Bucket Savonius Rotor using Computational Fluid Dynamics (CFD). *International Journal of Research in Mechanical*, *5762*(1), 46–51. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Flow+Physics+of+a+Three-Bucket+Savonius+Rotor+using+Computational+Fluid+Dynamics+(+CFD+)#0

Han, N., & Li, X. (2017). Study of static and dynamic performances of miniature Savonius-type wind energy harvesters. *Energy Procedia*, *105*, 119–124.

Hassan A. Hassan Saeed, Elmekawy, A. M. N., & Kassab, S. Z. (2019). Numerical study of improving Savonius turbine power coefficient by various blade shapes. *Alexandria Engineering Journal / Elsevier*, (March). Retrieved from

Hassanzadeh, R., Yaakob, O., Gholami, A., Pourmahdavi, M., Hosseinzadeh, M., Taheri, M. M., & Ahmed, Y. M. (2018). Experimental Investigation of an Innovative Configuration for New Marine Current Turbine. *Reaction Design,Elsevier Journals*, *119*(0960–1481).

He, D., Bai, H., Chan, C., & Li, K. (2019). Performance-based Optimizations on Savonius-type Vertical-axis Optimizations Symposium on Wind Turbines using Genetic Algorithm. *Energy Procedia / Elsevier*, *158*, 1–6.

Hsu, C.-J. (2017). Numerical Heat Transfer and Fluid Flow. *Nuclear Science and Engineering - Taylor & Francis*, *78*(2), 196–197. https://doi.org/10.13182/nse81-a20112

Huang, S. R., Ma, Y. H., Chen, C. F., Seki, K., & Aso, T. (2014). Theoretical and conditional monitoring of a small three-bladed vertical-axis micro-hydro turbine. *Energy Conversion and Management - Elsevier*, *86*, 727–734.

Ismail, M. F., & Vijayaraghavan, K. (2015). The effects of aerofoil profile modification on a vertical axis wind turbine performance. *Energy*, *80*, 20–31.

Jain, A. (2015). Control of Doubly Fed Induction Generator Connected to Variable Speed Wind Turbine. *IEEE International Conference on Technological Advancements in Power & Energy Control*, 500–505.

Jeon, K. S., Jeong, J. I., Pan, J. K., & Ryu, K. W. (2015). Effects of end plates with various shapes and sizes on helical Savonius wind turbines. *Renewable Energy*, *79*(1), 167–176.

Jin, X., Wang, Y., Ju, W., He, J., & Xie, S. (2018). Investigation into parameter influence of upstream deflector on vertical axis wind turbines output power via three-dimensional CFD simulation. *Renewable Energy*, *115*, 41–53.

Johannes, S S. (1929). *Rotor adapted to be driven by wind or flowing water*. Retrieved from https://www.google.com.my/patents/US1697574

Johannes, Savonius Sigurd. (1930). Rotor adapted to be driven by wind or flowing water. *Google Patents, US Patent*. Retrieved from https://www.google.com.my/patents/US1766765

Kacprzak, K., Liskiewicz, G., & Sobczak, K. (2013). Numerical investigation of conventional and modified Savonius wind turbines. *Renewable Energy - Elsevier*, *60*, 578–585.

Kalluvila, J. B. S., & Sreejith, B. (2018). Numerical and experimental study on a modified Savonius rotor with guide blades. *International Journal of Green Energy /Taylor &Francis*, *5075*(1543-5075 (Print)), 1543–5083.

Kang, C., Liu, H., & Yang, X. (2014). Review of fluid dynamics aspects of Savonius-rotor-based vertical-axis wind rotors. *Renewable and Sustainable Energy Reviews / Elsevier*, *33*, 499–508.

Kavade, R. K., & Ghanegaonkar, P. M. (2017). Design and Analysis of Vertical Axis Wind Turbine for Household Application. *Journal of Clean Energy Technologies*, *5*(5), 5–10.

Kerikous, E., & Thévenin, D. (2019). Optimal shape of thick blades for a hydraulic Savonius turbine. *Renewable Energy*, *134*, 629–638.

Kinzel, M., Mulligan, Q., & Dabiri, J. O. (2013). Energy exchange in an array of vertical-axis wind turbines. *Journal of Turbulence - Taylor & Francis*, *14*(6), 38–

39.

Korprasertsak, N., & Leephakpreeda, T. (2016). Analysis and optimal design of wind boosters for Vertical Axis Wind Turbines at low wind speed. *Journal of Wind Engineering and Industrial Aerodynamics*, *159*, 9–18.

Kozak, P. A. (2014). Effects of Unsteady Aerodynamics on Vertical-Axis Wind Turbine Performance VERTICAL-AXIS WIND TURBINE PERFORMANCE Submitted in partial fulfillment of the requirements for the degree of Master of Science in Mechanical and Aerospace Engineering in the Gradu. *Https://Www.Researchgate.Net/Publication/263161316*, (June).

Kumar, A., & Saini, R. P. (2017). Performance analysis of a single stage modi fi ed Savonius hydrokinetic turbine having twisted blades. *Renewable Energy*, *113*, 461–478.

Lee, J. H., Lee, Y. T., & Lim, H. C. (n.d.). Effect of twist angle on the performance of Savonius wind turbine. *Renewable Energy / Elsevier*, *89*, 231-244 , 2016, DOI: 10.1016/j.renene.2015.12.012.

Li, Q., Maeda, T., Kamada, Y., Murata, J., Furukawa, K., & Yamamoto, M. (2016). The influence of flow field and aerodynamic forces on a straight-bladed vertical axis wind turbine. *Energy*, *111*, 260–271.

Lim, Y. C., Chong, W. T., & Hsiao, F. B. (2013). Performance investigation and optimization of a vertical axis wind turbine with the omni-direction-guide-vane. *Procedia Engineering*, *67*(m), 59–69.

Loganathan, B., Chowdhury, H., Mustary, I., & Alam, F. (2015). An experimental study of a cyclonic vertical axis wind turbine for domestic scale power generation. *Procedia Engineering*, *105*(Icte 2014), 686–691.

Loganathan, B., Mustary, I., Chowdhury, H., & Alam, F. (2017a). Effect of sizing of a Savonius type vertical axis micro wind turbine. *Energy Procedia*, *110*(December 2016), 555–560.

Loganathan, B., Mustary, I., Chowdhury, H., & Alam, F. (2017b). Effect of Turbulence on a Savonius Type Micro Wind Turbine. *Energy Procedia*, *110*(December 2016), 549–554.

MacPhee, D., & Beyene, A. (2012). Recent Advances in Rotor Design of Vertical Axis Wind Turbines. *Wind Engineering / Elsevier*, *36*(6), 647–665.

Mahmoud, N. H., El-Haroun, A. A., Wahba, E., & Nasef, M. H. (2012). An experimental study on improvement of Savonius rotor performance. *Alexandria*

Engineering Journal, *51*(1), 19–25.

Mari, M., & Venturini, M. (2017). Performance evaluation of novel spline-curved blades of a vertical axis wind turbine based on the savonius concept. *The ASME 2016 International Mechanical Engineering Congress and Exposition IMECE2016 /November 11-17, 2016, Phoenix, Arizona, USA*, 1–13.

Mari, M., & Venturini Mauro, A. B. (n.d.). Performance evaluation of novel spline-curved blades of a vertical axis wind turbine based on the savonius concept. *Proceedings of the ASME 2016 International Mechanical Engineering Congress and Exposition IMECE2016*, (IMECE2016-65122), 1–13.

Marin, A., Kishore, R., Schaab, D. A., Vuckovic, D., & Priya, S. (2015). Micro Wind Turbine for Powering Wireless Sensor Nodes. *Energy Harvesting and Systems*, *3*(2), 717–720.

Marinić-Kragić, I., Vučina, D., & Milas, Z. (2018). Numerical workflow for 3D shape optimization and synthesis of vertical-axis wind turbines for specified operating regimes. *Renewable Energy*, *115*, 113–127.

Maroha, E., & Salyers, T. (2016). NUMERICAL INVESTIGATION OF NOVEL DESIGN OF SAVONIUS BLADE Rotations per Minute. *ASME 2016 Power Conference*, 1–15.

Mercado-colmenero, J. M., Rubio-paramio, M. A., Guerrero-villar, F., & Martin-doñate, C. (2018). A numerical and experimental study of a new Savonius wind rotor adaptation based on product design requirements. *Energy Conversion and Management*, *158*(December 2017), 210–234.

Mereu, R., Federici, D., Ferrari, G., Schito, P., & Inzoli, F. (2017). Parametric numerical study of Savonius wind turbine interaction in a linear array. *Renewable Energy - Elsevier*, *113*, 1320-1332-DOI:10.1016/j.renene.2017.06.094.

Mohamed, M. H., Ali, A. M., & Hafiz, A. A. (2015). CFD analysis for H-rotor Darrieus turbine as a low speed wind energy converter. *Engineering Science and Technology, an International Journal*, *18*(1), 1–13.

Mohammadi, M., Mohammadi, R., Ramadan, A., & Mohamed, M. H. (2018). Numerical investigation of performance refinement of a drag wind rotor using flow augmentation and momentum exchange optimization. *Energy*, *158*, 592–606.

Mohd, S., Rosly, N., Zulkafli, M. F., Mohamad Zainu, N. S. B., Abdullah, A., Shamsudin, S. S., & Wahab, A. A. (2016). Proposed design of wind turbine systems on a pickup truck. *ARPN J. of Engineering and Applied Sciences*, *11*, 11160.

Morshed, K. N., Rahman, M., Molina, G., & Ahmed, M. (2013). Wind tunnel testing and numerical simulation on aerodynamic performance of a three-bladed Savonius wind turbine. *International Journal of Energy and Environmental Engineering*, *4*(1), 18.

Nasef, M. H., El-Askary, W. A., AbdEL-hamid, A. A., & Gad, H. E. (2013). Evaluation of Savonius rotor performance: Static and dynamic studies. *Journal of Wind Engineering and Industrial Aerodynamics*, *123*, 1–11.

Nobile, R., Vahdati, M., Barlow, J. F., & Mewburn-Crook, A. (2014). Unsteady flow simulation of a vertical axis augmented wind turbine: A two-dimensional study. *Journal of Wind Engineering and Industrial Aerodynamics*, *125*, 168–179.

Nur Alom, U. K. S. (2017). Arriving at the Optimum Overlap Ratio for an Elliptical-bladed. *The ASME 2017 Gas Turbine India Conference GTINDIA2017*, *GT2017-641*, 1–10.

Ouahabi, M. H., Ichenial, M. M., Hajjaji, A. El, & Benabdelouahab, F. (2017). Application of the Turbulence Models at Low Reynolds Number for Horizontal - Axis Wind Turbine Design by using Computational Fluid Dynamics (CFD). *International Journal of Control and Automation*, *10*(7), 179–190.

Palencia Díaz, A., Jiménez Pajaro, G., & Utria Salas, K. (2015). Computational model of Savonius turbine. *Ingeniare. Revista Chilena de Ingeniería*, *23*(3), 406–412.

Patel, V., Eldho, T. I., & Prabhu, S. V. (2018). Theoretical study on the prediction of the hydrodynamic performance of a Savonius turbine based on stagnation pressure and impulse momentum principle. *Energy Conversion and Management*, *168*(April), 545–563.

Plourde, B. D., Abraham, J. P., Mowry, G. S., & Minkowycz, W. J. (2012). Simulations of Three-Dimensional Vertical-Axis Turbines for Communications Applications. *Wind Engineering*, *36*(4), 443–453.

Rashidi, M., Kadambi, J. R., & Chinchore, A. (2014). Computational Study of Savonius Wind Turbines. *Volume 7: Fluids Engineering Systems and Technologies*, V007T09A101. https://doi.org/10.1115/IMECE2014-39595

Reupke, P., & Probert, S. D. (1991). Slatted-blade Savonius wind-rotors. *Applied Energy / Elsevier*, *40*(1), 65–75.

Ricci, R., Romagnoli, R., Montelpare, S., & Vitali, D. (2016). Experimental study on a Savonius wind rotor for street lighting systems q. *Applied Energy Journal, Elsevier*, *161*, 143–152.

Ross, I., & Altman, A. (2011). Wind tunnel blockage corrections: Review and application to Savonius vertical-axis wind turbines. *Journal of Wind Engineering and Industrial Aerodynamics*, *99*(5), 523–538.

Roy, Sukanta and Ducoin, A. (2016). Unsteady analysis on the instantaneous forces and moment arms acting on a novel Savonius-style wind turbine. *Energy Conversion and Management Elsevier*, *121*, 281--296.

Roy, & Saha, U. K. (2016). Imece2013-64001 Numerical Investigation To Assess an Optimal Blade Profile for. *ASME. ASME International Mechanical Engineering Congress and Exposition*, *6A Energy*, 1–9. Retrieved from http://proceedings.asmedigitalcollection.asme.org/proceeding.aspx?articleid=1858367

Roy, S., & Ducoin, A. (2016). Unsteady analysis on the instantaneous forces and moment arms acting on a novel Savonius-style wind turbine. *Energy Conversion and Management - Elsevier*, *121*, 281–296.

Roy, S., & Saha, U. K. (2013). Computational study to assess the influence of overlap ratio on static torque characteristics of a vertical axis wind turbine. *Procedia Engineering*, *51*(NUiCONE 2012), 694–702.

Roy, S., & Saha, U. K. (2015). Wind tunnel experiments of a newly developed two-bladed Savonius-style wind turbine. *Applied Energy / Elsevier*, *137*, 117–125.

Saha, U. K., & Rajkumar, M. J. (2006). On the performance analysis of Savonius rotor with twisted blades. *Renewable Energy / Elsevier*, *31*(11), 788,

Santhakumar, S., Palanivel, I., & Venkatasubramanian, K. (2018). An experimental study on the rotational behaviour of a Savonius wind turbine for two-lane highway applications. *Journal of the Brazilian Society of Mechanical Sciences and Engineering*, *40*(4).

Sanusi, A., Soeparman, S., Wahyudi, S., & Yuliati, L. (2017). Performance analysis of a combined blade savonius wind turbines. *International Journal of Fluid Machinery and Systems - Turbomachinery Society of Japan, Korean Society for Fluid Machinery, Chinese*, *10*(1), 54–62.

Selyutskiy, Y. D., Klimina, L. A., Masterova, A. A., Hwang, S. S., & Lin, C. H. (2019). Savonius rotor as a part of complex systems. *Journal of Sound and Vibration*, *442*, 1–10.

Shaheen, M., & Abdallah, S. (2016). Development of efficient vertical axis wind turbine clustered farms. *Renewable and Sustainable Energy Reviews*, *63*, 237–244.

Shahizare, B., Nik-Ghazali, N., Chong, W. T., Tabatabaeikia, S., Izadyar, N., & Esmaeilzadeh, A. (2016). Novel investigation of the different Omni-direction-guide-vane angles effects on the urban vertical axis wind turbine output power via three-dimensional numerical simulation. *Energy Conversion and Management*, *117*, 206–217.

Shahzad, A., Asim, T., Mishra, R., & Paris, A. (2013). Performance of a vertical axis wind turbine under accelerating and decelerating flows. *Procedia CIRP - Elsevier*, *11*, 311–316.

Sharma, K. K., & Gupta, R. (2014). Speed Variation in Savonius Rotors with Respect to Overlap. *International Review of Applied Engineering Research / Research India Publications*, *4*(3), 233–240.

Spera, D. A. (2009). Wind Turbine Technology: Fundamental Concepts of Wind Turbine Engineering. *Solar Energy /Elsevier, 62*(2), XVII.

Srinivasan, C., Ajithkumar, G., Arul, S., Arulprasath, G., & Dharunbabu, T. M. (2017). Design of Combined Savonius-Darrieus Wind Turbine. *IOSR Journal of Mechanical and Civil Engineering*, *14*(02), 60–70.

Sun, X., Cao, Z., Zhuang, Y., Huang, D., & Cao, Y. (2017). Numerical modeling and optimization of a power augmented S-type vertical axis wind turbine. *International Journal of Green Energy*, *14*(6), 540–546.

Svorcan, J., Stupar, S., Komarov, D., Peković, O., & Kostić, I. (2013). Aerodynamic design and analysis of a small-scale vertical axis wind turbine. *Journal of Mechanical Science and Technology*, *27*(8), 2367–2373.

Tahani, M., Rabbani, A., Kasaeian, A., Mehrpooya, M., & Mirhosseini, M. (2017). Design and numerical investigation of Savonius wind turbine with discharge flow directing capability. *Energy*, *130*, 327–338.

Talukdar, P. K., Kulkarni, V., & Saha, U. K. (2018). Performance Characteristics of Vertical-Axis Off-Shore Savonius Wind and Savonius Hydrokinetic Turbines. *ASME 2018 37th International-Conference on Ocean, Offshore and Arctic Engineering*, V010T09A020.

Talukdar, P. K., Sardar, A., Kulkarni, V., & Saha, U. K. (2018). Parametric analysis of model Savonius hydrokinetic turbines through experimental and computational investigations. *Energy Conversion and Management*, *158*(December 2017), 36–49.

Tartuferi, M., D'Alessandro, V., Montelpare, S., & Ricci, R. (2015). Enhancement of savonius wind rotor aerodynamic performance: A computational study of new blade shapes and curtain systems. *Energy*, *79*(C), 371–384.

Toja-Silva, F., Kono, T., Peralta, C., Lopez-Garcia, O., & Chen, J. (2018). A review of computational fluid dynamics (CFD) simulations of the wind flow around buildings for urban wind energy exploitation. *Journal of Wind Engineering and Industrial Aerodynamics*, *180*, 66–87.

Ubando, A., Maralit, A., Nyanasengeran, K., Pua, M. T., & Moran, R. L. (2015). Computational Fluid Dynamics Analysis and Optimization of a Savonius Vertical Axis Wind Turbine for De La Salle University Campus. *Presented at the DLSU Research Congress 2015 De La Salle University, Manila, Philippines March 2-4, 2015 Computational*, *3*, 1–10.

Vicente, J., Antonio, H., & Prisco, A. (2012). A review on the performance of Savonius wind turbines. *Renewable and Sustainable Energy Reviews*, *16*(5), 3054–3064.

Wenehenubun, F., Saputra, A., & Sutanto, H. (2015). An experimental study on the performance of Savonius wind turbines related with the number of blades. *Energy Procedia*, *68*, 297–304.

Williams, R., Rocha, J., Matida, E., & Nitzsche, F. (2017). ASSESSMENT OF SURFACE-BASED AEROACOUSTIC NOISE FROM BLADES OF A VERTICAL-AXIS WIND TURBINE. *The ASME 2014 International Mechanical Engineering Congress and Exposition IMECE2014/Montreal, Quebec, Canada*, *November 1*, 1–6.

Wong, K. H., Chong, W. T., Sukiman, N. L., Poh, S. C., Shiah, Y. C., & Wang, C. T. (2017). Performance enhancements on vertical axis wind turbines using flow augmentation systems: A review. *Renewable and Sustainable Energy Reviews*, *73*(June 2016), 904–921.

Xu, Z., Feng, Y., Zhao, C., Huo, Y., Li, S., & Hu, X. (2018). Experimental and numerical investigation on aerodynamic performance of a novel disc-shaped wind rotor for the small-scale wind turbine. *Energy Conversion and Management*, *175*(May), 173–191.

Yao, Y. X., Tang, Z. P., & Wang, X. W. (2013). Design based on a parametric analysis of a drag driven VAWT with a tower cowling. *Journal of Wind Engineering and Industrial Aerodynamics*, *116*, 32–39.

Zeid, D., Abid, S. M., Sarhan, K., & D, A. (2012). Experimental study of the internal overlap ratios effect on the performance of the savonius wind rotor. *Journal of Engineering and Technology*, *1*(1), 15–21.

Zeiner-Gundersen, D. H. (2014). A vertical axis hydrodynamic turbine with flexible foils, passive pitching, and low tip speed ratio achieves near constant RPM. *Energy*, *77*, 297–304. https://doi.org/10.1016/j.energy.2014.08.008

Zhang, B., Song, B., Mao, Z., Tian, W., Li, B., & Li, B. (2017). A novel parametric modeling method and optimal design for Savonius wind turbines. *Energies - Multidisciplinary Digital Publishing Institute*, *10*(3).

Zheng, M., Li, Y., Tian, Y., Hu, J., Zhao, Y., & Yu, L. (2015). Effect of blade installation angle on power efficiency of resistance type VAWT by CFD study. *International Journal of Energy and Environmental Engineering*, *6*(1).

Zhou, T., & Rempfer, D. (2013). Numerical study of detailed flow field and performance of Savonius wind turbines. *Renewable Energy*, *51*, 373–381.